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- Economics of Water Management for
- Cotton and Grain Sorghum Production,
- High Plains

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R. D. LEWIS, DIRECTOR, COLLEGE STATION, TEXAS

## SUMMARY

Improved water management affords an alternative to the measures commonly used to offset the effects of a declining water supply. In many situations, where the continued decline in water levels has offset the increase in water supply from new wells, lowered pumps and installation of underground delivery systems, a changed water management program may be the only means of avoiding a return to dryland farming.

Because of competition for water during the first 2 weeks of August, the independently developed cotton and grain sorghum irrigation practices that maximize yields cannot be advantageously combined on the same farm. Therefore, the management program must be modified to minimize the effects of competing demands for water.

Four alternative water management systems may be followed if the operator prepares for them in advance. These alternatives, designated in this report as water management systems 1, 2, 3 and 4, differ only after August 1. With system 1, which uses the smallest amount of water, only cotton is irrigated after August 1. With system 2, which uses a little more water than system 1, a full-season hybrid sorghum is the only crop irrigated after August 1. System 3 combines the cotton irrigation program of system 1 with irrigation of sorghum hybrids planted about July 1. In system 4, the first water application on the full-season sorghum hybrids is made as in system 2, after which the water is shifted to the late-planted sorghum hybrids. Since systems 3 and 4 are heavy water users, they should not be used regularly.

The cotton-grain sorghum planting ratio of 1 acre of cotton to 1.75 acres of grain sorghum (seven-eighths acre of full-season sorghum hybrids and seven-eighths acre of short-season sorghum hybrids) permits the use of the most advantageous water management system on August 1. The cotton-grain sorghum planting ratio of 1:1.75 acres is about the same as the ratio of cotton to sorghum under the 1957 cotton acreage allotment programs.

For appraisal purposes, the cotton-sorghum planting ratio of 1:1.75 is converted to a management unit of 2.75 acres. Grain sorghum pre-planting irrigation occurs at a time when the water is not needed on cotton; grain sorghum receives a postplanting irrigation only when it is more profitable to use the water on sorghum than on cotton. The management unit approach permits a determination of the most economic water use, irrespective of the head of water

available. Thus, the water management system that is more profitable with a head of 135 gallons per minute also is most profitable with a head of 540 gallons per minute, in that its use will return more or lose less than other alternatives.

Based on the 1946-56 average prices received for cotton lint, cottonseed and grain sorghum, water management system 2 is most profitable. At the yield levels used, system 2 returned more or lost less than system 1 in 9 of the 11 years, 1946-56.

With management system 2 and 1946-56 average cotton and sorghum grain prices, the tenant's annual residual return—the amount available to defray his portion of water costs—on a typical 320-acre fully irrigated farm would be \$22.15 per acre. This constitutes his breakover point for water costs; that is, his expenditures for water cannot exceed this annual amount over a period of time without dissipating his operating capital or reducing his income below what he might obtain from comparable dryland farming. Irrigated farming is more profitable than dry farming, his principal alternative, to the extent that his annual per acre water costs are below the breakover point.

The annual residual return, under the same conditions, to the landlord of this typical farm would be \$14.40 per acre. This constitutes the landlord's maximum feasible expenditure for water—his breakover point. It is the amount available to defray the cost of providing and maintaining a well and pump, to pay interest on the cost of irrigation facilities, exclusive of the pump power unit and to provide a return on that part of his investment that exceeds the value of the undeveloped land plus irrigation development costs per acre. Like the tenant, the landowner cannot exceed his breakover point for water expenditures without reducing his net income below that from comparable dryland farming.

The owner-operator's breakover point for water expenditures is slightly higher than the total of the tenant and landlord at all price levels. He combines the receipts and, with one exception, the expense of both tenant and landowner in one operation. The landlord has some farm supervisory expenses that are not required or that are taken care of in normal operations by the owner-operator. With system 2, and with cotton and sorghum grain prices at the 1946-56 average, the breakover price for water for an owner-operator of the typical 320-acre farm is about \$38 per acre.

## ACKNOWLEDGMENTS

This study includes the work of a number of agencies and individuals concerned with various phases of the hydrologic and agricultural problems of the High Plains. The principal sources of information are listed under "Literature Ci-

ted." Particular credit is due E. L. Langsford and Max Tharp, Farm Economics Research Division, Agricultural Research Service, U. S. Department of Agriculture, for their assistance.

# *Economics of Water Management for Cotton and Grain Sorghum Production, High Plains*

WM. F. HUGHES, A. C. MAGEE, DON JONES and EARNEST L. THAXTON, JR.\*

CONTINUED CHANGE HAS BEEN characteristic of agriculture in the High Plains. Some changes have been made gradually; others, such as mechanization and irrigation, developed rapidly once they were underway. Irrigated agriculture in parts of the High Plains now is faced with further adjustment. The extent of this adjustment will be governed largely by local water supply conditions. In some parts of the area, relatively few adjustments may be required. In others, where the water supply has deteriorated, the adjustment may require a return to dryland farming.

Irrigation began in the area about 1911 but was of little consequence until after the mid-1930's. Technological improvements and higher prices for farm products during the years just before, during and immediately after World War II stimulated a substantial expansion of irrigated farming. By 1948, about 1.4 million acres were being irrigated from 10,000 wells (1). Irrigation development since 1948 has continued at the accelerated rates of the late forties. The 1955 Census of Agriculture reports that in 1954 there were slightly more than 2.5 million acres of irrigated land in the 12 counties where most of the irrigated lands are located. This was an increase of slightly more than 1 million acres over the 1949 acreage reported by the Census. The most recent, though unofficial, estimate is that in 1957 in the same 12 counties about 3.5 million acres were irrigated from approximately 34,000 wells (2).

The expansion in irrigated acreage since 1950 has been accompanied by a sharp increase in the rate of water use per acre. Water use rose from an average of 11 acre-inches per acre in 1947-49 to 17 acre-inches during the drouth years of 1950-56 (3).<sup>1</sup> This accelerated demand on ground water supplies, combined with lessened recharge during the drouth, has caused a decline in water levels and a reduction in well yields.

\*Respectively, agricultural economist, Farm Economics Research Division, Agricultural Research Service, U. S. Department of Agriculture; professor, Department of Agricultural Economics and Sociology, Texas Agricultural Experiment Station; formerly superintendent and formerly assistant irrigation engineer, Substation No. 8, Lubbock, Texas.

<sup>1</sup>Based on information compiled from various sources by W. L. Broadhurst, chief hydrologist, High Plains Underground Water Conservation District No. 1, Lubbock. See also "Use of Irrigation Water on the High Plains" (3).

A systematic water-level measuring program was started in 1937 by the State Board of Water Engineers and the U. S. Geological Survey. The changes in water levels recorded as a result of this measuring program are shown in Figure 1. Since 1937 there has been an average decline of approximately 42 feet in regional static water levels. The decline has not been distributed evenly over the area. It ranges from about 10 feet on the outer edges to over 80 feet in small areas near the east-central part of the ground water basin. Throughout most of the more heavily developed portions, the total decline ranges from 30 to 50 feet (4).

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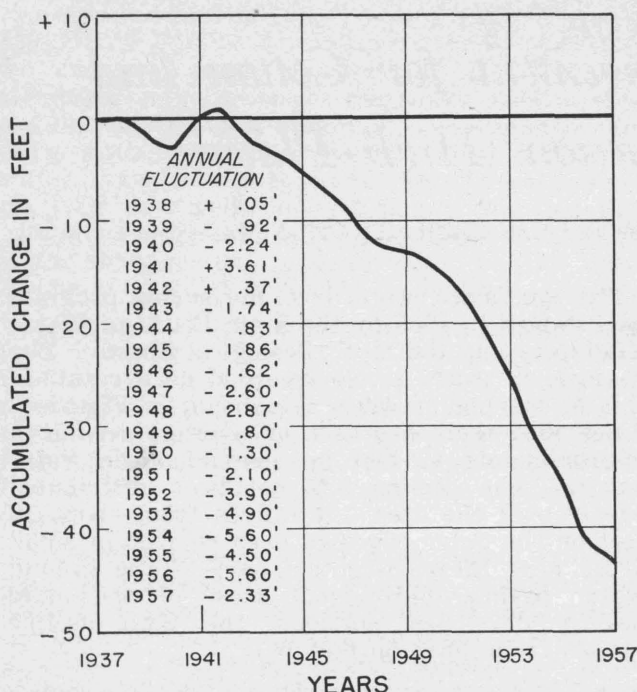


Figure 1. Accumulated and annual decline in regional static water levels, High Plains, 1937-57. (Data from U. S. Geological Survey and Board of Water Engineers.)

Before 1949, the decline in static water level was moderate and its effects, except in isolated areas, were economically insignificant. Since 1949, the decline has exhibited a progressive trend, and combined with a decrease in well yields, it is becoming economically significant. The principal physical effect of a lessened water supply is reflected by a reduction in the amount of water that can be made available within the period of time that it can be used to best advantage.

Changes in the water level during the past 8 years suggests a possible physical exhaustion of the water supplies, particularly in those areas where the water bearing formations are thin. The cost of meeting part of this decline, reported in TAES Bulletin 828, indicates that economic exhaustion is likely to precede physical exhaustion (5).

Between 1950-54 the rate of water use increased 54 percent; static water levels declined 18 feet between 1950-54 and 12.4 feet between 1955-57. Heretofore, these declines have been offset by drilling new wells, lowering pumps, increasing the hours of pump operation, installing closed delivery systems, land leveling and more intensive land preparation and farming practices. These measures have been effective, but expensive. The cost of such measures installed during 1950-54 averaged above \$6,600 per farm; total water cost rose from an average of about \$7 per acre during 1947-49 to about \$15 in 1954 (6, 7).

As water levels decline, the effectiveness of some of the measures previously used to offset

this condition likely will be short lived. Once their effectiveness is lost, the operator has the alternatives of adding more expensive and possibly short-lived measures, provided he has not already exhausted this possibility, of reducing irrigated acreage, or of applying less water per acre.

Management programs involving combinations of crops, varieties, planting dates and irrigation schedules, and rates of water use afford an alternative to the measures heretofore relied upon to meet reductions in water supplies. Where these measures have been installed and their effectiveness has been lost or diminished, some modification of existing water management programs may be the only alternative to a return to dryland farming.

## PURPOSE

This study evaluates some of the more promising alternative irrigation management programs and is reported in two parts. The first part concerns the most economic use of water under various crop-water management programs. The second part deals with the determination of the maximum expenditure for irrigation water that is economically feasible. It is based on an evaluation of the results that might be expected on an established irrigated farm assuming (1) adaptations of the individually developed cotton and grain sorghum irrigation programs that have maximized cotton and grain sorghum yields in experimental work and general practice, (2) the crop production practices and requirements in common use during 1955, (3) the use of hybrid grain sorghum and (4) the crop yields obtained in station and off-station experimental work, adjusted to a level that might be expected under general farm conditions.

The possible effects of using fertilizers or improved cultural practices are not included. If future research results show that these measures are practicable, their contributions can be appraised separately. The study emphasizes the short-run considerations of the farmer interested in improving his situation. The possible adverse effects on regional water supplies are considered but not specifically evaluated.

## MOST ECONOMIC WATER USE

Where water, rather than land, is the chief limiting factor, as in the High Plains, the primary management objective is the development of a cropping and water-use program that will provide maximum returns per unit of water use, rather than maximum yields per acre. The management problem is complicated by changing cost-price relationships, acreage allotment programs and the lack of suitable alternative cash crops.

Acreage allotments and the lack of suitable alternative cash crops may impair the operator's



opportunity to get the highest returns from water but they simplify his management problem by reducing the number of alternatives. Thus, the problem of maximizing returns from water involves a determination of the most remunerative use of water applied in specified amounts at specific times on cotton or grain sorghum. The price of cotton and grain sorghum and the yield response of each crop to a specific amount of water applied at a particular time provide the basis for selecting the most economic water-use program.

The quantity of water that can be made available during a given period of time is governed by the yield of the well or wells providing the farm water supply. Well yields differ among farms and between wells; however, except for their effect on water costs, these differences do not affect the determination of the most economic water use.

The most economic water use program does not necessarily mean a profitable irrigation enterprise. With irrigation already established, the most economic use is the one that provides the largest return. It will contribute to the success of an irrigated enterprise, but water and associated costs may be such that the whole enterprise is unprofitable.

### Basis for Crop-water-management Programs

Variations in weather before and after planting, as well as from year to year, preclude strict adherence to any rigid timetable of planting dates, irrigation schedules or rates of water application. Under High Plains conditions, any crop or water-management program must be flexible; it must be designed to permit adjustment as dictated by weather or the price outlook.

All crops have definite stages of development in which a shortage of water has a depressing effect on growth and subsequent yields.

These stages of development also are the periods of peak water requirement. Although weather may vary the time by a few days, the period of peak water requirement can be expected to begin on cotton and grain sorghum about 60 and 45 days, respectively, after planting (Figure 2).

The moisture provided by irrigation permits a wide choice in crop varieties and planting dates. Selection of varieties and adjustments in planting dates to minimize or to prevent the simultaneous occurrence of peak water use periods by crops provides one method of coping with a limited water supply.

All management programs involve some sacrifice of the yield levels that might be realized with a water supply sufficient to meet simultaneous peak water requirements. A knowledge of the probable effects of water shortages and of the yield response of individual crops irrigated at particular stages of plant growth is basic in determining the most advantageous use of water. In addition, certain limitations imposed by plant growth characteristics must be taken into account.

A management system should be designed around:

**Crop growth characteristics.** Cotton is indeterminate in its fruiting habits—it will continue to grow and fruit until killed by frost. Because of this, it can use water effectively over an extended period of time. Grain sorghum is terminal in its fruiting habits—it fruits only once. Because of this, it is extremely critical in its water requirements.

**Water requirements.** The rate of water use by cotton and grain sorghum is shown in Figure 2. The daily rate of use by cotton increases just before the first bloom stage, which is approximately 60 days after planting and continues at an accelerated rate until the bolls begin to mature. The daily rate of water use by grain sorghum increases at a faster rate than cotton,

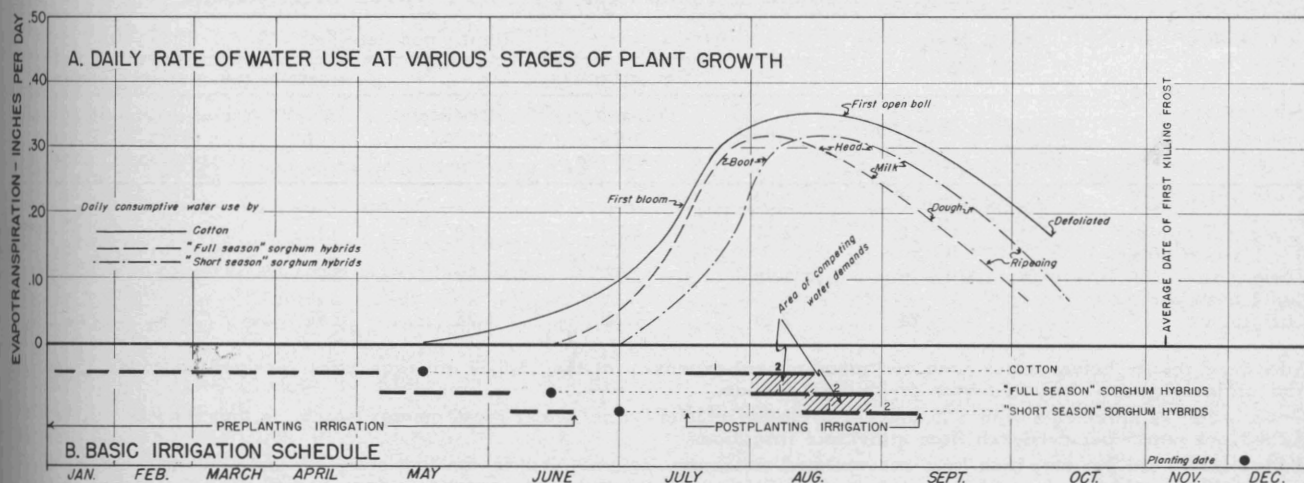


Figure 2. Basic irrigation schedules related to water requirements of cotton and grain sorghum at various stages of plant growth.

TABLE 1. AVERAGE YIELDS PER ACRE OF COTTON AND GRAIN SORGHUM RELATED TO NUMBER AND TIME OF IRRIGATION<sup>1</sup>

Irrigation practices	Cotton lint	Grain sorghum	
		Full-season hybrid	Short-season hybrid
		Pounds	
Dryland (no irrigation)	190	900	720
Preplanting irrigation only	400	2,700	2,250
Preplanting irrigation plus			
One July irrigation	440		
One July and one August irrigation	490		
One August irrigation		3,300	2,750
Two August irrigations		3,780	3,150

<sup>1</sup>Yields obtained at the Lubbock station and in outlying field tests, adjusted to a level that might reasonably be expected under general farm conditions.

reaching a peak of 0.33 inches a day about 45 days after planting.<sup>2</sup> The estimates of daily use shown in Figure 2 reflect the average rate of water use between measurements.

Because of its fruiting habits, cotton can withstand a short period of water stress without a heavy reduction in yield. Water stress at any stage of development reduces grain sorghum yields, particularly at the early bloom and soft dough stages. Water stress at these stages has reduced yields on the average by 48 and 25 percent, respectively (8).

The total water requirements of cotton and grain sorghum vary from year to year depending on planting date, seasonal temperatures, relative humidity and wind movement. More water is required in a hot season than in a relatively cool one. Results of studies reported in TAES Bulletins 838 and 846 show that rainfall provides about half the total water required to

produce an irrigated cotton or grain sorghum crop. These studies also show that an irrigation program which provides an average ¼ acre-inch of available water per day during July and August for cotton, and during July, August and September for grain sorghum meets the normal water requirements of these crops (9, 10).

*Irrigation programs.* Details of the irrigation program that maximizes cotton yields are given in TAES Bulletin 838 (9). Similar information for grain sorghum is given in TAES Bulletin 846 (10). Essentially, the programs consist of a preplanting irrigation for both crops followed by two postplanting irrigations timed to prevent water stress at critical stages of plant growth (Figure 2).

The preplanting irrigation, preferably in one application, provides enough water to bring moisture levels in the soil profile up to field capacity throughout the root zone. Six-foot profiles of Amarillo fine sandy loam or Pullman clay loam, the predominant soil types, will hold approximately 9 and 12 inches of available water, respectively (9). The actual amount of water that must be applied to bring these soils up to field capacity will depend on the amount of water already stored in the soil.

The time of preplanting irrigation is not necessarily critical. When cotton follows cotton in the crop rotation, 3 or 4 months are available for preplanting irrigation. When cotton follows sorghum, about 200 days are available for the preplanting application of water.

Irrigation water applied before planting provides a larger increase in yield per unit of water applied than water applied after planting (Table 1). Also, at 1946-56 average cotton and grain sorghum prices, water applied before planting to cotton land produces a greater net return than water similarly applied on grain sorghum (Table 2). Because of the difference in planting dates for cotton and sorghum, preplant-

<sup>2</sup>Data compiled by Morris Bloodworth, E. L. Thaxton, Jr. and others. (Unpublished data.)

TABLE 2. ESTIMATED ADDED RETURNS FROM DIFFERENT WATER APPLICATIONS

Number and type of irrigations	Quantity of water <sup>2</sup>		Return per acre-inch <sup>1</sup>					
			Per irrigation <sup>3</sup>			Average per acre-inch applied <sup>4</sup>		
	Per irrigation	Accumulative	Cotton	Full-season grain sorghum	Short-season grain sorghum	Cotton	Full-season grain sorghum	Short-season grain sorghum
	— Acre-inch —					Dollars		
Preplant irrigation	12	12	3.16 <sup>5</sup>	2.71 <sup>5</sup>	1.90 <sup>5</sup>	3.16 <sup>5</sup>	2.71 <sup>5</sup>	1.90 <sup>5</sup>
Plus 1 postplanting irrigation	6	18	1.79	2.07	1.72	2.70	2.50	1.84
Plus 2 postplanting irrigations	6	24	2.25	1.04	1.35	2.59	2.28	1.72

<sup>1</sup>Added net return, before water, land and management expenses, at the 1946-56 average price received for cotton, cottonseed and grain sorghum. Irrigated over dryland production.

<sup>2</sup>Gross water requirements with 66.6 percent irrigation efficiency, net water requirements two-thirds that shown.

<sup>3</sup>Added net return per acre-inch from individual irrigations.

<sup>4</sup>Added net return per acre-inch from accumulated water application. That is, the first entry, all three columns, reflects the average added net return from 12 acre-inches of water, the second entry, the average return from the use of 18 acre-inches of water, and the third the average return from 24 acre-inches of water.

<sup>5</sup>Net gain over average return from dryland farming.



ing irrigation of both crops is possible ( Figure 2). Thus, preplanting irrigation is a basic practice in all water-management programs.

The irrigation program that maximizes cotton and grain sorghum yields includes two irrigations after planting. These applications are timed to restore soil moisture levels and prevent water stress at critical stages of plant development (Figure 2). As with preplanting irrigation, the amount of water required to restore soil moisture levels depends on temperature and on the amount of precipitation received. For best results even in the driest season, the postplanting applications of water on cotton should not exceed 4 acre-inches of available water per acre applied in a 14 to 18-day schedule. The first postplanting application should begin at the first bloom stage of plant development, approximately 60 days after planting, and the second should be applied immediately following the conclusion of the first postplanting application (9). Postplanting irrigation on grain sorghum involves the same rate of water application as cotton, but because of the more critical nature of sorghum water requirements, it should be applied in a shorter schedule beginning about 45 days after planting (10).

A 4-inch (net) water application will restore soil moisture levels and meet the peak daily water requirements of cotton and grain sorghum for about 9.5 and 12 days, respectively. It will meet the normal daily water requirement on both crops for 16 days. Larger water applications could lead to crop damage. Smaller amounts would not provide an adequate water supply unless the application was based on a shorter schedule. Also, water losses from drying soil take a proportionately greater share of a small water application.

Because of the relatively short cotton-growing season, irrigation should be terminated about mid-August. Withholding irrigation after this time may reduce yields, but it produces a consistently higher quality of cotton. The growing competition from synthetics and the wide discounts for short fibers and low grades emphasize the need for consideration of quality cotton in all management programs. Irrigation of grain sorghum after late August or early September, except on late plantings, seldom benefits a properly irrigated crop (10).

*Planting dates.* The usual planting season for cotton ranges from late April through May, depending on the weather. The soil usually is too cool for rapid cottonseed germination before late April. Yields of cotton planted in June generally are low (11). Experience at the Lubbock substation shows that the best stands and fastest growth are obtained on cotton planted from May 10 to May 20. Cotton planted during this period has a better chance of survival because it is more likely to escape the damaging effects of cool nights, cold winds, blowing sand and

seedling diseases. Low yields on late-planted cotton and the relatively short cotton-growing season make it undesirable to delay cotton planting; consequently, there is little or no room for adjustment in cotton-planting dates.

The planting season for grain sorghum ranges from late April through June. The preferred planting time, however, is between June 10 and June 20, approximately 30 days later than the most desirable cotton-planting time. Sorghum planted during this time enters its period of peak water requirement when rainfall and temperature relations likely will be most favorable. Sorghum planted earlier grows off slowly and enters the period of peak water requirement at a time when rainfall and temperature relations likely will be less favorable.

Until recently, sorghum planted during the last part of June or early July did not produce a consistently satisfactory yield. Development of the higher yielding sorghum hybrids has changed this. Some of the sorghum hybrids, such as those in the 590 to 611 group, designated as "short-season hybrids," are suitable for late-season planting. Others, which outyield standard varieties by 20 percent, require the full growing season to realize their potential. The latter group is designated "full-season hybrids." Sorghum hybrids permit adjustment in planting dates to reduce the conflict in irrigation water requirements of cotton and sorghum that have restricted sorghum irrigation during the critical period, August 1-15.

*Crop yields.* The average cotton and grain sorghum yields with an irrigation program as outlined are shown in Table 1. These yields reflect the average production per acre that may be obtained from a preplanting irrigation, the average amount that may be added by one postplanting application of water and the average amount that may be added by two postplanting applications of water. The net value added by successive water increments—the part of the yields that is attributable to a single irrigation—provides the basis for selecting the most advantageous place of water use.

### ***Basic Crop-water-management Program***

A crop-water-management program incorporating the most advantageous planting dates and the cotton and grain sorghum irrigation program that maximizes yields of both crops is used to determine the most economic use of water. Part of the details of this program are shown in Figure 2.

This crop-water-management program includes preplanting irrigation as a standard practice. Because of the relatively high return per acre-inch of water applied before planting, this practice must be included in any program designed to obtain the highest return from the use of water (Table 2).



Since the amount of precipitation during the crop year cannot be determined in advance, a rate of water use near the maximum amount that may be required was adopted. Using gross water requirements, the program would require for each crop a rate of 12 acre-inches per acre applied in one or two applications before planting, and for postplanting irrigation, two applications of 6 acre-inches per acre each. With an irrigation efficiency of 66.6 percent, the net preplanting water requirements are 8 acre-inches per acre and the postplanting requirements are 4 acre-inches per acre for each application.

The midpoints of the preferred planting periods, May 15 for cotton and June 15 for grain sorghum, were selected as dates for planting all of the cotton and half the grain sorghum acreage. The other half of the grain sorghum acreage would be planted to a short-season hybrid about July 1 (Figure 2).

The postplanting irrigation on cotton would be applied in a 16-day schedule beginning approximately 60 days after planting. With a May 15 planting date, the first application of water on cotton would begin about July 15. The second postplanting irrigation, also applied in a 16-day schedule would follow immediately after the first and terminate shortly after August 15.

Postplanting irrigation on grain sorghum would be applied in a 14-day schedule beginning approximately 45 days after planting for the full-season hybrids and 40 days after planting for the short-season hybrids. With a June 15 planting date, the first irrigation on the full-season sorghum hybrids would begin on or about August 1. The second would start immediately after the first irrigation was concluded (Figure 2). With a July 1 planting date, the first postplanting irrigation on the short-season hybrids would begin about August 10, followed immediately by the second application, which would end during the first part of September.

Figure 2 shows that serious conflicts in demand for water would be encountered about August 1, if the independently developed cotton and grain sorghum irrigation programs were combined. Because of these conflicting demands for water, it is not feasible to use the basic crop-water-management program entirely. The full basic program can be used only if (1) the water supply is doubled to meet the simultaneous August 1-15 demands, or (2) the acreage irrigated during the postplanting period is reduced approximately 50 percent.

Neither of these alternatives provides an economical approach. Increasing the farm water supply is an expensive way of reducing conflicting water demands; moreover, the added drain on water resources would aggravate further the water supply situation. The approximate cost of increasing and maintaining farm water supplies is given in TAES Bulletin 828 (5). Decreasing the irrigated acreage reduces

total operating costs some, but increases the overhead water cost per acre and materially reduces farm income.

Since it is not feasible to use the crop-water-management program that maximizes crop yields, the next best approach is to adopt a variation that incorporates the basic program as much as possible. This involves a modification of the basic crop-water-management program beginning at the time of the first conflict in demand for water about August 1.

### *Alternative Water-management Systems*

There are five alternative water-management programs that may be followed beginning about August 1, if the operator has prepared for them in advance. For convenience, these water-management programs are designated water management systems 1, 2, 3, 4 and 5. Systems 1 to 4 are based on restricted crop acreages under crop-control programs. System 5 is based on the unrestricted use of cotton acreage.

For systems 1 to 4, a management unit of 1 acre of cotton, seven-eighths acre of full-season sorghum hybrids and seven-eighths acre of short-season sorghum hybrids was adopted. Because of the difference in irrigation schedules (16 days on cotton, 14 days on grain sorghum) only seven-eighths acre of grain sorghum can be irrigated for each acre of cotton, and the cotton-grain sorghum planting ratio that permits the widest choice in use of water during August is 1 acre of cotton to seven-eighths acre of full-season sorghum hybrids and seven-eighths acre of short-season sorghum hybrids. This planting ratio of 1 acre of cotton to each 1.75 acres total grain sorghum is approximately the average cotton-grain sorghum planting ratio under 1957 cotton acreage-allotment programs.

For management system 5, which is based on unrestricted cotton acreage, the management unit is 2 acres of cotton and three-fourths acre of short-season sorghum hybrids. System 5 is included to compare production situations with and without cotton acreage restrictions, and to appraise situations where cotton acreage allotment exceeds the acreage that can be irrigated during the postplanting irrigation season. The effects of each individual irrigation on a particular crop can be appraised separately (Table 1). About August 1, the date of first conflict in water use, the operator has the choice of irrigating cotton for the second time or of irrigating the full-season sorghum hybrids for the first time. Similarly, on or about August 15, if he has prepared for these alternatives in advance, the operator has a further choice of irrigating the full-season sorghum hybrid for the second time or of applying water to the short-season hybrid for the first time.

The section on crop growth characteristics shows that the benefits of the second postplanting irrigation on grain sorghum, whether full-

TABLE 3. RATIO OF COTTON TO GRAIN SORGHUM ACREAGE, IRRIGATION SCHEDULES, AND GROSS WATER USE PER MANAGEMENT UNIT ALTERNATIVE WATER MANAGEMENT SYSTEM<sup>1</sup>

Water management system	Crops	Management unit	Irrigations		Gross water use		
			Pre-planting <sup>2</sup>	Post-planting	Pre-planting	Post-planting	Total <sup>3</sup>
		Acres	Number		Acre-inches		
1	Cotton	1	1	2	12.0	12.0	24.0
	Grain sorghum, full-season	7/8	1	0	10.5	0	10.5
	Grain sorghum, short-season	7/8	1	0	10.5	0	10.5
	Total for management unit	2 3/4	1		33.0	12.0	45.0
2	Cotton	1	1	1	12.0	6.0	18.0
	Grain sorghum, full-season	7/8	1	2	10.5	10.5	21.0
	Grain sorghum, short-season	7/8	1	0	10.5	0	10.5
	Total for management unit	2 3/4	1		33.0	16.5	49.5
3	Cotton	1	1	2	12.0	12.0	24.0
	Grain sorghum, full-season	7/8	1	0	10.5	0	10.5
	Grain sorghum, short-season	7/8	1	2	10.5	10.5	21.0
	Total for management unit	2 3/4	1		33.0	22.5	55.5
4	Cotton	1	1	1	12.0	6.0	18.0
	Grain sorghum, full-season	7/8	1	1	10.5	5.3	15.8
	Grain sorghum, short-season	7/8	1	2	10.5	10.5	21.0
	Total for management unit	2 3/4	1		33.0	21.8	54.8
5	Cotton	1	1	2	12.0	12.0	24.0
	Cotton	1	1	0	12.0	0	12.0
	Grain sorghum, short-season	3/4	1	2	9.0	9.0	18.0
	Total for management unit	2 3/4	1		33.0	21.0	54.0

<sup>1</sup>Based on an irrigation efficiency of 66.6 percent.

<sup>2</sup>Preplanting irrigation in one or two, preferably one, application.

<sup>3</sup>Totals reflect the gross amount of water applied to the individual crops in the management unit and the total amount, gross, per management unit of 2 3/4 acres. Gross water use per acre would be 16.4, 18.0, 20.2, 19.9 and 20.7 acre-inches, respectively, in management systems 1 through 5, respectively.

season or short-season hybrids, cannot be realized unless the first postplanting irrigation has been applied. The August 1-15 conflict in demands for water between cotton and the full-season sorghum hybrids cannot be resolved in favor of cotton without sacrificing the yield increments from both of the postplanting irrigations on sorghum. The last postplanting irrigation on sorghum can be foregone, however, at the expense of only that part of the yield attributable to the last irrigation.

These alternatives provide the basis for water management systems 1 to 4, any one of which may be followed after August 1, the date of first water use conflict.

In all management systems, water is applied on sorghum land before planting at a time that does not conflict with irrigation of cotton land or grain sorghum, after planting, when the price of sorghum grain makes it more profitable to irrigate sorghum. The return per management unit of 2.75 acres, therefore, provides a basis for determining the most profitable use of water regardless of the head of water available. For example, if one management unit in a particular management system is more profitable than a management unit in another, an increase in the number of management units does not change the relationship.

The planting ratios, irrigation schedules and use of water per management unit in the five systems are shown in Table 3. The plan of water use after August 1 for the five systems is shown in Figure 3.

The quantity of water use per management unit for preplanting irrigation is the same in all five systems. Water use after planting differs between the various alternative systems, depending on the acreage covered in postplanting irrigation (Table 3 and Figure 3). The total water use per management unit in systems 3, 4 and 5 is approximately 22 percent greater than in system 1 and 10 percent greater than in system 2.

### Evaluation of Alternative Management Systems

Production, irrigation practices and water requirements before August 1 are the same for all five systems. Since systems 1 to 4, the four alternative systems, stem from a common base,

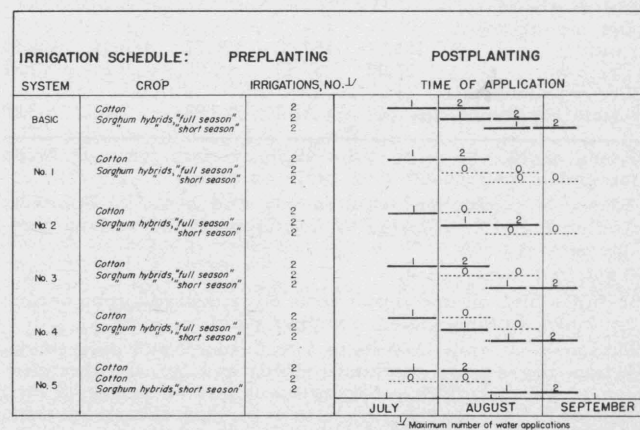


Figure 3. Number and approximate time of irrigation in the basic and five alternative water management systems.



TABLE 4. ESTIMATED CROP PRODUCTION AND GROSS VALUE PER MANAGEMENT UNIT ALTERNATIVE WATER MANAGEMENT SYSTEMS<sup>1</sup>

Water management system	Cotton		Grain sorghum		Gross value per management unit <sup>2</sup>
	Pro-duction of lint	Gross value <sup>2</sup> <sup>3</sup>	Pro-duction	Gross value <sup>2</sup>	
	Pounds	Dollars	Pounds	— — Dollars — —	
1	490	181.30	4,331	95.71	277.01
2	440	162.80	5,276	116.60	279.40
3	490	181.30	5,119	113.13	294.43
4	440	162.80	5,644	124.73	287.53
5	890	329.30	2,362	52.20	381.50

<sup>1</sup>Management unit in systems 1 to 4 consists of 1 acre cotton,  $\frac{7}{8}$  acre full-season sorghum hybrids and  $\frac{7}{8}$  acre short-season sorghum hybrids. Management unit in system 5 consists of 2 acres cotton and  $\frac{3}{4}$  acre of short-season sorghum hybrids.

<sup>2</sup>Based on 1946-56 average prices received for cotton, cottonseed and grain sorghum.

<sup>3</sup>Includes value of cottonseed.

the choice of the system to follow at the time of the first water-demand conflict will be governed first by prospective added net returns per management unit in the alternative systems, and second by the amount of water required to obtain these returns.

TABLE 5. ESTIMATED NET RETURNS PER MANAGEMENT UNIT, ALTERNATIVE WATER MANAGEMENT SYSTEMS<sup>1</sup>

Item	Water management system				
	1	2	3	4	5
	— — — — — Dollars — — — — —				
Gross Receipts	277.01	279.40	294.43	287.52	381.50
Specified expenses <sup>2</sup>					
Power and machinery	29.44	29.44	29.44	29.44	40.62
Materials <sup>3</sup>	10.09	10.09	10.09	10.09	17.64
Labor, including water spreading	15.67	15.95	16.45	16.33	21.00
Harvest and associated costs	51.17	47.32	51.64	47.54	82.35
Direct water costs <sup>4</sup>	16.92	18.80	21.06	20.68	20.30
Total specified expenses	123.29	121.60	128.68	124.08	181.91
Net returns to management and overhead					
Per management unit <sup>5</sup>	153.72	157.80	165.75	163.45	199.59
Per acre	55.89	57.37	60.26	59.42	72.57
Per acre-inch of water applied <sup>6</sup>	3.42	3.19	2.99	2.98	3.70

<sup>1</sup>Based on 1955-56 costs and 1946-56 average prices received for cotton, cottonseed and grain sorghum.

<sup>2</sup>Based on production requirements and costs in Appendix Tables 2 and 3, adjusted for requirements of various management systems.

<sup>3</sup>Seed and insecticides.

<sup>4</sup>Includes fuel, oil and repair costs on typical 540 gpm, engine equipped, butane fueled pumping plant.

<sup>5</sup>Management units in systems 1 to 4 consist of 1 acre cotton,  $\frac{7}{8}$  acre full-season sorghum hybrids and  $\frac{7}{8}$  acre short-season sorghum hybrids. Management unit in system 5 consists of 2 acres cotton and  $\frac{3}{4}$  acre of short-season sorghum hybrids.

<sup>6</sup>Gross water use of 45, 49.5, 55.5, 54.8, and 54 acre-inches for systems 1, 2, 3, 4 and 5, respectively.

Since the choice between alternative water-management systems is not made until the first conflict in demand for water occurs (about August 1), almost all crop production expenses except harvest costs, will be the same irrespective of the management system used. Table 1 shows that the output resulting from single applications of water can be appraised separately if the applications are considered in proper sequence. Also, the cost of making a single application of water and the cost of harvesting the added yields can be determined (Appendix Tables 2 and 3). The prospective added net return per increment of water use, per irrigation in this instance, then can be determined by multiplying the added production by the prospective price and subtracting the added costs.

Since the irrigation schedule is 16 days on cotton and 14 days on both types of grain sorghum, only seven-eighths acre of grain sorghum can be irrigated during the postplanting season for each 1 acre of cotton. This difference in irrigation schedule is the basis for the cotton-grain sorghum planting ratio in the management unit. Thus, where the choice lies between irrigating cotton or grain sorghum on August 1, the comparison is based on the prospective added net returns from one irrigation on 1 acre of cotton or two irrigations on seven-eighths acre of grain sorghum.

The following comparison between systems 1 and 2 illustrates this point. On August 1, the place of water application should be selected: it may be on cotton, where an application of 6 acre-inches of water will produce 50 pounds of lint cotton and 80 pounds of seed, or, on a full-season hybrid, where 10.5 acre-inches of water in two applications on seven-eighths acre will produce 945 pounds of grain ( $7/8 \times [3780-2700]$ ) (Table 1).

Obviously, the prices of cotton and grain sorghum have an important bearing on the prospective added net returns from irrigating after August 1. For instance, comparison based on 1955-56 cost and the prices received for cotton lint, cottonseed, and grain sorghum during 1945-56 shows that when 1 pound of lint and 1.6 pounds of seed are worth more than 20 pounds of grain sorghum, it is more profitable to irrigate cotton; when 1 pound of lint and 1.6 pounds of seed are worth less than 20 pounds of grain sorghum, it is more profitable to irrigate sorghum.

If the added net returns from 50 pounds of cotton lint and 80 pounds of cottonseed exceed the added net returns from 945 pounds of grain sorghum, the low water-use system 1 in which cotton receives 2 postplanting irrigations and grain sorghum none, will provide a greater added net return than system 2. If, on the other hand, 945 pounds of grain sorghum provide a greater added net return, system 2, in which cotton receives one, and grain sorghum, two postplanting irrigations, will be more profitable.



TABLE 6. ADDED NET RETURNS PER ACRE-INCH OF WATER USED AFTER AUGUST 1, ALTERNATIVE MANAGEMENT SYSTEMS<sup>1 2</sup>

Water management systems	Water used	Added costs	Added returns	Added net returns	Added net returns per acre-inch
	Acre-inches	Dollars			
1	6.00	7.17	18.48	11.31	1.88
2	10.50	3.98	20.88	16.90	1.61
3	16.50	11.05	35.87	24.82	1.50
4	15.75	5.90	28.99	23.09	1.47

<sup>1</sup>Based on 1955-56 costs and 1946-56 average prices.

<sup>2</sup>Because of the different cotton acreage in system 5, the results from the use of water after August 1 are not comparable with those of the other four systems.

In situations where system 1 is more profitable than system 2, system 3 would be still more profitable, but would involve a heavier use of water. System 3 differs from system 1 only in that beginning at the conclusion of the cotton-irrigating season, 10.5 acre-inches of water in two applications are made on seven-eighths acre of short-season sorghum hybrids. In system 3, the expenditure of 16.5 acre-inches of water after August 1 produces 50 pounds of cotton lint, 80 pounds of cottonseed and 790 pounds of grain sorghum.

When system 2 is more profitable than system 1, there also is an alternative, system 4, requiring a heavier water use. In system 4, like its lower-water-using counterpart system 2, cotton is not irrigated during August. A post-planting application of 5.25 acre-inches of water is applied on seven-eighths acre of full-season sorghum hybrids during the first 2 weeks of August, after which 10.5 acre-inches of water in two irrigations are made on seven-eighths acre of short-season sorghum hybrids. The 15.75 acre-inches of water applied after August 1 provide 1,315 pounds of sorghum grain (790 pounds

TABLE 7. CROPLAND ORGANIZATION AND PRODUCTION ON TYPICAL 320-ACRE TENANT-OPERATED IRRIGATED AND DRYLAND FARMS

Crop	Irrigated farm <sup>1</sup>			Dryland farm		
	Acres	Production		Acres	Production	
		Total	Tenant's share		Total	Tenant's share
		— Pounds —			— Pounds —	
Cotton	112	49,280	36,960	112	21,280	15,960
Grain Sorghum	196	590,950	394,164	196	176,400	117,659
Miscellaneous	12			12		
Total	320			320		

<sup>1</sup>Acreage and production based on use of water management system 2 for 112 management units of 2.75 acres each. See Table 4 for cotton and grain sorghum yields per management unit.

as in system 3 plus  $7/8 \times [3300-2700]$ ) (Table 1).

The comparisons of alternative systems 1, 2, 3 and 4 pertain to differences in crop production and in water use during August, the principal period of wateruse conflict.

Production and gross values per management unit in the five management systems are shown in Table 4. Gross values are based on

TABLE 8. ESTIMATED RECEIPTS, EXPENSES AND RESIDUAL RETURNS TO WATER, 320-ACRE IRRIGATED FARM OPERATED UNDER WATER MANAGEMENT SYSTEM 2

Item	Type of operator		
	Tenant operator	Landlord	Owner operator
	Dollars		
Gross receipts, crop sales <sup>1</sup>			
Cotton, including seed	13,664	4,555	18,219
Sorghum grain	8,711	4,349	13,060
Total receipts	22,375	8,904	31,279
Expenses exclusive of water costs			
Specified operating expenses			
Labor <sup>2</sup>	1,786		1,786
Power and machinery (excluding pumping costs)	3,297		3,297
Materials (seed, insecticides, etc.)	1,131		1,131
Harvest and associated costs	4,957	342	5,299
Miscellaneous <sup>3</sup>	558		558
Total	11,729	342	12,071
Specified farm overhead expenses			
Taxes <sup>4</sup>		258	258
Maintenance, depreciation and insurance on farm improvements <sup>5</sup>		1,500	1,500
Supervisory <sup>6</sup>		445	
Capital charge on land <sup>7</sup>		1,920	1,920
Total	11,729	4,465	15,749
Alternative management income <sup>8</sup>	3,824		3,824
Total expenses excluding water	15,553	4,465	19,573
Residual returns to water <sup>9</sup>			
Per farm	6,822	4,439	11,706
Per acre irrigated	22.15	14.41	38.00
Per acre-foot of water used	13.35		22.90

<sup>1</sup>At 1946-56 average prices received for cotton, cottonseed and grain sorghum (Appendix Table 1).

<sup>2</sup>All labor, including operator, unpaid family and hired labor at \$1.00 per hour.

<sup>3</sup>Five percent of specified operating expenses to cover transportation of supplies and general supervision.

<sup>4</sup>Based on average total ad valorem taxes per acre in Lubbock and Hale counties.

<sup>5</sup>7.5 percent on \$20,000 worth of farm improvements, excluding irrigation facilities.

<sup>6</sup>5.0 percent of gross receipts to cover expenses associated with general management.

<sup>7</sup>Five percent interest charge on land with an undeveloped (preirrigation development) value of \$120 per acre.

<sup>8</sup>Management income of a 320-acre similarly organized dryland farm at the same cost-price levels.

<sup>9</sup>The maximum economically feasible or breakover point for water expenditures.

TABLE 9. TENANT'S BREAKOVER POINT FOR WATER EXPENDITURES PER ACRE AT SPECIFIED COTTON LINT AND GRAIN SORGHUM PRICES, 320-ACRE IRRIGATED FARM OPERATED UNDER WATER MANAGEMENT SYSTEM 2<sup>1</sup>

Seasonal average price per pound of lint cotton <sup>2</sup>	Seasonal average price per hundredweight of grain sorghum										
	\$3.25	\$3.00	\$2.75	\$2.50	\$2.25	\$2.00	\$1.75	\$1.50	\$1.25	\$1.00	\$0.75
Cents	Dollars										
34	32.83	30.49	28.14	25.80	23.47	21.12	18.78	16.44	14.10	11.76	9.42
33	32.14	29.80	27.46	25.12	22.78	20.44	18.10	15.76	13.42	11.08	8.74
32	31.46	29.12	26.78	24.44	22.10	19.76	17.42	15.08	12.74	10.40	8.06
31	30.78	28.44	26.10	23.76	21.42	19.08	16.74	14.40	12.06	9.72	7.38
30	30.10	27.76	25.42	23.08	20.74	18.40	16.06	13.72	11.38	9.04	6.70
29	29.42	27.08	24.74	22.40	20.06	17.72	15.38	13.04	10.70	8.36	6.02
28	28.74	26.40	24.06	21.72	19.38	17.04	14.70	12.36	10.02	7.68	5.34
27	28.05	25.71	23.37	21.03	18.69	16.35	14.01	11.67	9.33	6.99	4.65
26	27.37	25.03	22.69	20.35	18.01	15.67	13.33	10.99	8.65	6.31	3.97
25	26.69	24.35	22.01	19.67	17.33	14.99	12.65	10.31	7.97	5.63	3.29
24	26.01	23.67	21.33	18.99	16.65	14.31	11.97	9.63	7.29	4.95	2.61

<sup>1</sup>Based on use of 112 management units of 2.75 acres each, with yields shown for management system 2 in Table 4.

<sup>2</sup>Includes value of cottonseed at \$60 per ton at all price levels.

the 1946-56 average price received for cotton lint, cottonseed and grain sorghum. Since systems 1 to 4 are identical up to August 1, differences for these systems in the gross value per management unit shown in the last column of the table reflect the returns from alternative water uses after August 1.

Specified crop production expenses shown in Table 4 are based on the production requirements and costs shown in Appendix Tables 2 and 3. Differences in specified production costs per management unit reflect (1) differences in the cost of labor required to spread water, which is affected by the length of the irrigation season, (2) differences in harvesting and associated costs which are associated with differences in yield and (3) differences in direct water costs, which are proportional to the amount of water used in the various management systems.

Table 5 shows for all five water-management systems, net returns per acre and per acre-inch of water applied. System 1, which has the

lowest water use of systems 1 to 4, provides the lowest return per acre but the highest return per acre-inch of water.

Since management systems 1 to 4 differ only in the place of water use after August 1, the return per acre-inch of water applied before August 1 will be the same in all of these management systems. The net returns to management and crop overhead per acre-inch of water applied after August 1 are shown in Table 6. The returns for management system 5 are not included in Table 6 because the cotton-grain sorghum planting ratio differs from that of the other systems.

Systems 1 and 2 provide the highest net return per acre-inch of water applied after August 1 and are the principal alternatives.

Systems 3 and 4, the heavier water-using alternatives to systems 1 and 2, respectively, are virtually eliminated as a continued practice. Total water use per acre under systems 3 and 4 is 20 acre-inches per acre, approximately 3 acre-

TABLE 10. TENANT'S BREAKOVER POINT FOR WATER EXPENDITURES PER ACRE AT SPECIFIED COTTON LINT AND GRAIN SORGHUM PRICES, 320-ACRE IRRIGATED FARM OPERATED UNDER WATER MANAGEMENT SYSTEM 1<sup>1</sup>

Seasonal average price of lint cotton per pound <sup>2</sup>	Seasonal average price per hundredweight of grain sorghum										
	\$3.25 <sup>3</sup>	\$3.00 <sup>3</sup>	\$2.75 <sup>3</sup>	\$2.50 <sup>3</sup>	\$2.25 <sup>3</sup>	\$2.00 <sup>3</sup>	\$1.75	\$1.50	\$1.25	\$1.00	\$0.75
Cents	Dollars										
34							20.48	18.69	16.92	15.16	13.39
33							19.65	17.87	16.11	14.34	12.57
32							"	17.05	15.29	13.52	11.75
31							"	16.24	14.47	12.70	10.94
30							"	15.42	13.65	11.88	10.12
29							"	14.60	12.83	11.07	9.30
28							"	13.78	12.02	10.25	8.48
27							"	"	11.20	9.43	7.66
26							"	"	10.38	8.61	6.85
25							"	"	9.56	7.79	6.03
24							"	"	8.74	6.98	5.21

<sup>1</sup>Based on use of 112 management units of 2.75 acres each with yields shown for management system 1 in Table 4.

<sup>2</sup>Includes the value of seed with seed priced at \$60 per ton, all price levels.

<sup>3</sup>At these price levels management system 2 provides a higher breakover point than management system 1.

inches per acre greater than the 1950-54 average rate of water use.<sup>3</sup> Figure 1 shows that the water resources of the area will not support indefinitely an increase in the rate of water use. Also, the additional 10.5 acre-inches of water per management unit required for system 3 over system 1 provide a net added return of only \$1.29 per acre-inch. Similarly, the additional 5.25 acre-inches of water required for system 4 over system 2 provide a net added return of only \$1.17 per acre-inch. Thus, the additional water required with systems 3 and 4 provides a net added return per acre-inch that is about one-third less than the added returns from systems 1 and 2, their respective alternatives, and only about one-third of the possible net return from water applied before planting (Table 2).

Systems 1 and 2 apparently afford the most desirable alternatives under conditions of decreasing water supplies and cotton acreage controls. Lifting of cotton acreage controls could alter the situation. Without controls, management system 5, which includes 2 acres of cotton per management unit, affords a better short-run alternative than system 3 or system 4. Total water use with system 5 is similar to that of systems 3 and 4, but the net return per acre-inch of water and per management unit is the greatest of the five alternative management systems considered (Tables 3 and 5).

These comparisons of returns to the five management systems are based on the 1946-56 average price received for cotton lint, cottonseed and grain sorghum (Appendix Table 1). A change in cotton or grain sorghum prices would materially affect prospective returns and would affect the selection of the alternative system to be followed after August 1.

<sup>3</sup>Based on information compiled from various sources by W. L. Broadhurst, chief hydrologist, High Plains Underground Water Conservation District No. 1, Lubbock, Texas.

TABLE 11. LANDOWNER'S BREAKOVER POINT FOR WATER EXPENDITURES PER ACRE AT SPECIFIED COTTON LINT AND GRAIN SORGHUM PRICES, 320-ACRE IRRIGATED FARM OPERATED UNDER WATER MANAGEMENT SYSTEM 2<sup>1</sup>

Seasonal average price per pound of lint cotton <sup>2</sup>	Seasonal average price per hundredweight of grain sorghum										
	\$3.25	\$3.00	\$2.75	\$2.50	\$2.25	\$2.00	\$1.75	\$1.50	\$1.25	\$1.00	\$0.75
Cents	Dollars										
34	16.77	15.70	14.62	13.55	12.48	11.41	10.34	9.27	8.20	7.13	6.07 <sup>3</sup>
33	16.60	15.53	14.46	13.39	12.32	11.25	10.18	9.11	8.04	6.97	5.90 <sup>3</sup>
32	16.43	15.36	14.29	13.22	12.15	11.08	10.01	8.94	7.87	6.80	5.73 <sup>3</sup>
31	16.26	15.19	14.12	13.05	11.98	10.91	9.84	8.77	7.70	6.63	5.56 <sup>3</sup>
30	16.09	15.02	13.95	12.88	11.81	10.74	9.67	8.60	7.53	6.46	5.39 <sup>3</sup>
29	15.92	14.85	13.78	12.71	11.64	10.57	9.50	8.43	7.36	6.29	5.22 <sup>3</sup>
28	15.75	14.68	13.61	12.54	11.47	10.40	9.33	8.26	7.19	6.12	5.05
27	15.58	14.51	13.44	12.37	11.30	10.23	9.16	8.09	7.02	5.95	4.88
26	15.41	14.34	13.27	12.20	11.13	10.06	8.99	7.92	6.85	5.78	4.71
25	15.24	14.17	13.10	12.03	10.96	9.89	8.82	7.75	6.68	5.61	4.54
24	15.07	14.00	12.93	11.86	10.79	9.72	8.65	7.58	6.51	5.44	4.37
24	14.90	13.83	12.76	11.69	10.62	9.55	8.48	7.41	6.34	5.27	4.20

<sup>1</sup>Based on use of 112 management units of 2.75 acres each, with yields shown for management system 2 in Table 4.

<sup>2</sup>Includes value of cottonseed at \$60 per ton at all price levels.

<sup>3</sup>At these price levels, water management system 1 would provide a slightly higher breakover point.

Appendix Table 1 shows that at the yield levels assumed, system 2, which concentrates on grain sorghum production after August 1, would have provided a higher net added return in 9 of the 11 years between 1946-56. Therefore, system 2 is analyzed further.

Considerations leading to the most advantageous irrigation management systems are the same irrespective of the head of water (gallons per minute) available. Because the postplanting irrigation program involves uniform quantities of water applied within definite time periods, differences in irrigation head affect the total acreage that can be irrigated seasonally but does not affect the most economic use of water. Therefore, although there are economies of scale with the larger irrigation heads, the most economic use of water with a head of 540 gallons per minute is, although on a reduced scale, also the most economic use with a head of 135 gallons per minute. See TAES Bulletin 851 (13).

## MAXIMUM FEASIBLE EXPENDITURES FOR WATER

Determination of the most economic water management system was based on a partial analysis involving only the irrigation season after August 1. Use of the most economic water management system contributes to the success of an irrigation enterprise by providing a greater return or a smaller loss than alternative systems that might be used under the same circumstances. To determine the profitability of an irrigation enterprise, the entire irrigation-management program, including costs of installation and operation, and its returns, must be considered in light of its contribution to the farm as a unit.

The second objective of this study was to determine the maximum feasible expenditure for water. Since costs are peculiar to a particular



set of conditions, and returns are related closely to prices received, determination of the maximum feasible expenditure for water involves a comparison of costs for a particular set of conditions with a number of cotton and grain sorghum price combinations.

The analysis is based on estimated returns on a 320-acre, fully irrigated farm using management system 2. Assumptions regarding labor, power, machinery and material requirements and costs are based on the data presented in Appendix Tables 2 and 3, adjusted to reflect the labor requirements and harvesting costs associated with yield levels of management system 2. Cotton and grain sorghum prices are the average prices received in 1946-56 (Appendix Table 1).

Water costs fall in two broad groups—operating and overhead. Operating costs include expenditures for fuel or energy, oil, repairs and maintenance. Overhead costs include interest on investment, taxes, depreciation and risk or insurance. This division of water costs parallels with some exceptions the usual distribution of water costs between tenant and landlord under typical third and fourth crop-share leases (12). Under the typical crop-share lease agreement, the tenant furnishes and maintains the pump power unit and all fuel and oil costs. The landlord provides and maintains the well and pump.

The maximum feasible expenditure for water is the maximum amount that a farm operator could pay for water without reducing his net income below what he would receive from dryland farming. This is the breakover point above which irrigation is no longer a profitable undertaking for the tenant operator or the landowner.

With an established irrigated farm, the overhead portion of water costs is considered only when it becomes necessary to replace equipment. The investment in irrigation facilities and equipment has been made, and the landowner's only alternative to continued irrigation is to pull his pump for salvage and return to dryland farming. Used equipment brings only a fraction of its new cost and a return to dryland farming results in a severe reduction in land values. Therefore, in most situations where the cost-price squeeze has reduced the landowner's return, it probably will be advantageous to continue irrigation until replacement of equipment becomes necessary.

### ***Tenant's Breakover Point for Water Expenditures***

Land use, cropland organization and production on typical 320-acre irrigated and dryland farms are shown in Table 7. The cropland used is equivalent to 112 management units of 2.75 acres each (Tables 3, 4 and 5).

The tenant's breakover point for water expenditure under a typical third and fourth crop-share lease at average 1946-56 prices is shown

in Table 8. It is determined by deducting the tenant's share of all costs, except water and management, from his share of gross receipts. This residual, less an allowance for alternative management return (see discussion to follow), defrays the tenant's water costs. The chief cost and return items summarized in Table 8 were derived as follows:

*Gross receipts.* Gross receipts are returns from the volume of production shown in Table 7 at 1946-56 average prices given in Appendix Table 1 prorated according to the division of crop receipts in a typical third and fourth crop-share lease (12).

*Specified operating expenses.* Labor, power and machinery and material costs are based on production requirements and costs for a typical 320-acre farm shown in Appendix Tables 2 and 3, adjusted for operations under water management system 2.

*Harvest and associated costs.* Harvest and associated costs are costs to the first market place. They are based on the 1955 costs and practices reported in TAES Bulletin 851 (13). Briefly, cotton harvesting costs are based on 80 percent handsnapping and 20 percent machine stripping of irrigated cotton at a handsnapping rate of \$1.75 and a machine-stripping rate of 75 cents per 100 pounds of seed cotton. Ginning costs are computed at 50 cents per 100 pounds of seed cotton for a season average of 1,900 pounds of handsnapped and 2,400 pounds of machine-stripped seed cotton per standard bale of lint. A further charge of \$3.50 per bale for bag and ties, plus 50 cents per bale for hauling also is included. Sorghum-harvesting costs are based on a custom rate of \$3 per acre, plus a grain-hauling charge of 6 cents per 100 pounds.

*Miscellaneous expenditures.* Miscellaneous expenditures are an allowance of 5 percent of the specified operating expenses to cover transportation of supplies, labor recruitment and other necessary farm service activities.

*Alternative management income.* Alternative management income is the income that might be obtained on a dryland farm of similar size and organization at the same price levels. The concept is employed in lieu of a family living allowance, which would otherwise be required. The alternative management income reflects the farm operator's income from his chief alternatives, short of leaving the farm, and as such it represents the amount that would be available for family expenses and risk-bearing.

*Residual returns to water.* Residual returns to water is the amount remaining after production costs, including farm overhead and management returns, have been subtracted. The tenant's portion of this is the amount that he can spend for water without depleting his operating capital or reducing his income below the income he would receive from dryland farming, his chief

alternative. Under the conditions assumed in Table 8, the tenant's breakover point for water expenditures is \$6,822 for the farm, and about \$22 and \$13, respectively, per acre irrigated and per acre-foot of gross water use. He will profit to the extent that his share of total farm water costs can be held below \$6,822.

In Table 8, the breakover points for water expenditure are based on the 1946-56 average price received for cotton lint, cottonseed and sorghum grain. The tenant's breakover point for water expenditures per acre at other prices for cotton lint and grain sorghum are shown in Table 9. The entries in Table 9 have been derived through the same process as the breakover point per acre presented in Table 8. The price received for cottonseed is held constant at \$60 per ton at all cotton lint price levels. Specified farm operating expenses and farm overhead expenses, with the exception of the alternative management income, are held constant at the 1955-56 levels used in Table 8. As the alternative management income is based on the operator's alternative income on a similar dryland farm, it has been adjusted at each respective price level to reflect the effects of similar price changes on management income on a dryland farm.

Variations in cotton or grain sorghum prices have an important bearing on the prospective net return to the alternative management systems. Tables 9 and 10 show the tenant's breakover point when the typical farm described in Table 7 is operated under management systems 2 and 1, respectively. In general, with grain sorghum prices at or below \$1.50 per hundred-weight, management system 1 provides a higher breakover point for water expenditures than does system 2 (Table 10).

With management system 2, where irrigation water is used on grain sorghum after August 1, a change in the price of grain sorghum of 25 cents per 100 pounds reduces the breakover point on the farm by \$2.35 per acre. With management system 1, where irrigation water is used on cotton after August 1, a similar change in the price of grain sorghum reduces the breakover point by \$1.77 per acre (Table 10).

A 1-cent per pound change in the price of cotton lint changes the breakover point 69 and 83 cents per acre for management systems 2 and 1, respectively (Tables 9 and 10).

### ***Landlord's Breakover Point for Water Expenditures***

The landowner's receipts and expenditures and the residual available to defray his portion of irrigation costs under a typical third and fourth crop-share lease are shown also in Table 8 (12).

The landowner's receipts reflect the sale of his part of the crop—the difference between "total production" and "tenant's share" in Table

7—at 1946-56 average prices (Appendix Table 1).

The landowner's "specified operation expenses" consist of the ginning cost on his one-fourth share of the cotton crop, based on the previously discussed ginning costs.

Specified farm overhead expenses of the landowner are explained in the footnotes to Table 8.

At 1946-56 average prices received for cotton lint, cottonseed and sorghum grain, the landowner's residual return amounts to \$14.41 per acre. This is the amount per acre that would be available to cover depreciation and maintenance costs on the irrigation facilities, exclusive of the pump power unit, and to provide a capital return on the landowner's total investment in irrigation developments (Table 8, footnote 8). If the landowner's total annual irrigation and added capital costs exceed \$14.41 per acre, the landowner's breakover point for water expenditures, his net income is reduced below that estimated for a comparable dryland farming operation.

The landowner's breakover point for water expenditures at the prices of cotton and sorghum grain used in Tables 9 and 10 are shown in Table 11. The entries in Table 11 are computed as in Table 8.

### ***Owner-operator's Breakover Point for Water Expenditures***

Except for the small charge of \$445 for supervision expenses for the landlord (Table 8), the estimated receipts and expenses for an owner-operator represent the sum of those for the tenant and landlord. Because of this, at all price levels, the owner-operator's breakover point for water expenditures is slightly greater than the total of the tenant's and the landowner's breakover points. At 1946-56 average prices received for cotton lint, cottonseed and grain sorghum, the owner-operator's breakover point for water expenditures is \$38 per acre. At the same price levels, the combined tenant's and landowner's breakover points total \$36.56 per acre (\$22.15 for the tenant + \$14.41 for the landowner).

At 1946-56 average prices, the owner-operator could spend \$38 per acre per year without reducing his net income below comparable dry-farm levels. This is the amount that would be available to defray the combined fuel, oil and engine costs and the interest, maintenance and depreciation costs on irrigation facilities and added capital costs of the landowner.

The owner-operator's breakover point at other price levels is not computed; however, it always will be slightly greater than the total of the breakover points for the tenant and landowner shown in Tables 9 and 11, respectively.

The calculations that lead to a determination of the breakover point per acre for water



expenditures do not include an allowance to cover the risks involved in the production of an irrigated crop. Mortgage indebtedness, interest rates and appraisal of risk are peculiar to individual situations; consequently, no attempt is made to determine their effects.

## OTHER SITUATIONS

The study reported here is based on a *particular* set of conditions including farm size, crop acreages, production requirements, production costs and crop yields. The results, however, can be adjusted to other situations. The production requirement and cost data in Appendix Tables 2 and 3 and the entries in Table 8 can be adjusted to individual situations. Adjustments to fit situations involving different farm organizations, crop yields, price levels, interest rates, or capital investments will give different residual returns or breakover prices for water. Where an individual cost or return item differs from that used, the entries in Tables 9 and 11 can be adjusted by the amount of this difference to reflect the breakover price for water.

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## APPENDIX TABLES

APPENDIX TABLE 1. PRICES RECEIVED FOR COTTON AND GRAIN SORGHUM, HIGH PLAINS, 1946-56<sup>1</sup>

Year	Cotton		Grain sorghum
	Lint per pound	Cottonseed per ton	Per hundred weight
	Cents	Dollars	
1946	28.55	97.50	2.23
1947	31.80	94.00	3.30
1948	29.20	70.50	2.17
1949	26.10	41.25	1.71
1950	39.90	96.00	1.73
1951	39.85	74.50	2.34
1952	30.40	72.50	2.85
1953	29.20	52.50	2.23
1954	31.05	59.50	2.15
1955	29.70	45.50	1.57
1956	29.70	63.00	2.03
Average	31.40	69.70	2.21

<sup>1</sup>"Agricultural Prices," U. S. Department of Agriculture.



APPENDIX TABLE 2. PREHARVEST REQUIREMENTS FOR PRODUCING IRRIGATED AND DRYLAND COTTON AND GRAIN SORGHUM, BY MAJOR SOIL TYPES, HIGH PLAINS, 1955<sup>1</sup>

Soil type and type of farming operation	Machine requirements per acre	Man-labor requirements per acre				Tractor fuel per acre <sup>2</sup>	Seed per acre <sup>3</sup>	Insecticide applications per acre	Average irrigations per season
		Tractor operator	Hoe	Irrigation	Total				
		Hours				Gallons	Pounds	— Number —	
Sandy soils									
Irrigated cotton	4.16	4.16	5.20	2.08	11.44	16.6	48.0 <sup>4</sup>	3.5 <sup>5</sup>	3.5
Dryland cotton	1.55	1.55	3.20		4.75	6.2	30.0 <sup>4</sup>		
Irrigated grain sorghum	2.90	2.90		1.86	4.76	11.6	8.5		3.0
Dryland grain sorghum	1.55	1.55			1.55	6.2	6.0		
Heavy soils									
Irrigated cotton	4.75	4.75	5.40	1.62	11.77	19.0	48.0 <sup>4</sup>	3.5 <sup>5</sup>	3.0
Irrigated grain sorghum	3.02	3.02	2.00	1.73	6.75	12.1	8.5		3.3

<sup>1</sup>Adapted from TAES Bulletin 851 (13).

<sup>2</sup>Butane.

<sup>3</sup>Seeding rates per planting: irrigated cotton, 32 pounds; dryland cotton, 20 pounds; irrigated grain sorghum, 7 pounds; dryland grain sorghum, 4 pounds.

<sup>4</sup>Weight of seed before delinting.

<sup>5</sup>An average rate of 2 early applications and 1½ late-season applications.

<sup>6</sup>Depends on rainfall. With rainfall, 1 or 2 early applications; without rainfall, no application.

APPENDIX TABLE 3. PREHARVEST COSTS PER ACRE FOR LABOR, POWER AND MATERIALS OTHER THAN WATER USED TO PRODUCE COTTON AND GRAIN SORGHUM, HIGH PLAINS, AT SPECIFIED TYPES OF FARMS BY MAJOR SOIL TYPES, 1955 PRICES<sup>1 2</sup>

Soil type and size and type of farm	Power and machinery cost	Labor costs				Seed cost <sup>3</sup>	Insecticide cost <sup>4</sup>	Total specified costs <sup>5</sup>
		Machine operation	Hoeing	Irrigation labor	Total labor			
		Dollars						
Sandy soils: 320-acre farm								
Dryland cotton	4.88	1.47	2.08		3.55	1.95		10.38
Irrigated cotton	17.82	3.95	3.38	1.98	9.31	3.12	4.75	35.00
Dryland grain sorghum	3.22	1.47			1.47	.42		5.11
Irrigated grain sorghum	6.64	2.75		1.77	4.52	.60		11.76
160-acre farm								
Irrigated cotton	21.62	3.95	3.38	1.98	9.31	3.12	4.75	38.80
Irrigated grain sorghum	8.34	2.75		1.77	4.52	.60		13.46
Heavy soils: 320-acre farm								
Irrigated cotton	17.08	4.51	3.51	1.54	9.56	3.12	4.75	34.51
Irrigated grain sorghum	7.39	2.87	1.30	1.64	5.81	.60		13.80
160-acre farm								
Irrigated cotton	19.78	4.51	3.51	1.54	9.56	3.12	4.75	37.21
Irrigated grain sorghum	9.19	2.87	1.30	1.64	5.81	.60		15.60

<sup>1</sup>Adapted from Table 3, TAES Bulletin 851 (13).

<sup>2</sup>Based on requirements presented in Appendix Table 2.

<sup>3</sup>Delinted and treated cottonseed at 6.5 cents per pound; grain sorghum seed at 7 cents per pound.

<sup>4</sup>Material cost of 50 cents per acre for early application, \$2.50 per acre custom rate for late application. Machine labor and fuel costs of early application included in machine and machine operator costs. See footnote 5, Appendix Table 2.

<sup>5</sup>Includes cost of machinery, fuel, oil, grease repair, labor, seed and insecticides.

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Location of field research units of the Texas Agricultural Experiment Station and cooperating agencies

## State-wide Research



The Texas Agricultural Experiment Station is the public agricultural research agency of the State of Texas, and is one of ten parts of the Texas A&M College System

## ORGANIZATION

IN THE MAIN STATION, with headquarters at College Station, are 16 subject-matter departments, 2 service departments, 3 regulatory services and the administrative staff. Located out in the major agricultural areas of Texas are 21 substations and 9 field laboratories. In addition, there are 14 cooperating stations owned by other agencies. Cooperating agencies include the Texas Forest Service, Game and Fish Commission of Texas, Texas Prison System, U. S. Department of Agriculture, University of Texas, Texas Technological College, Texas College of Arts and Industries and the King Ranch. Some experiments are conducted on farms and ranches and in rural homes.

THE TEXAS STATION is conducting about 400 active research projects, grouped in 25 programs, which include all phases of agriculture in Texas. Among these are:

## OPERATION

Conservation and improvement of soil	Beef cattle
Conservation and use of water	Dairy cattle
Grasses and legumes	Sheep and goats
Grain crops	Swine
Cotton and other fiber crops	Chickens and turkeys
Vegetable crops	Animal diseases and parasites
Citrus and other subtropical fruits	Fish and game
Fruits and nuts	Farm and ranch engineering
Oil seed crops	Farm and ranch business
Ornamental plants	Marketing agricultural products
Brush and weeds	Rural home economics
Insects	Rural agricultural economics
	Plant diseases

Two additional programs are maintenance and upkeep, and central services.

*Research results are carried to Texas farmers, ranchmen and homemakers by county agents and specialists of the Texas Agricultural Extension Service*

AGRICULTURAL RESEARCH seeks the WHATS, the WHYS, the WHENS, the WHEREs and the HOWS of hundreds of problems which confront operators of farms and ranches, and the many industries depending on or serving agriculture. Workers of the Main Station and the field units of the Texas Agricultural Experiment Station seek diligently to find solutions to these problems.

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